

COLOR CONVERSION DEVICE AND COLOR CONVERSION METHOD

BACKGROUND OF THE INVENTION

The present invention relates to data processing used for a full-color printing related equipment such as a printer, a video printer, a scanner or the like, an image processor for forming computer graphic images or a display device such as a monitor. More specifically, the invention relates to a color conversion device and a color conversion method for performing color conversion from image data in the form of a first set of three color data of red, green and blue, or cyan, magenta and yellow, to a second set of three color data of red, green and blue, or cyan, magenta and yellow.

Color conversion in printing is an indispensable technology for compensating deterioration of image quality due to color mixing property due to the fact that the ink is not of a pure color, or the non-linearity (in the hue) of the image-printing, and to output a printed image with a high color reproducibility. Also, in a display device such as a monitor or the like, color conversion is performed in order to output (display) an image having desired color reproducibility in accordance with conditions under which the device is used or the like when an inputted color signal is to be displayed.

Conventionally, two methods have been available for the foregoing color conversion: a table conversion method and a matrix calculation method.

A representative example of the table conversion method is a three-dimensional look-up table method, in which the image data represented by red, green and blue (hereinafter referred to as R, G, and B) are input, to output an image data of R, G, and B stored in advance in a memory, such as a ROM, or complementary color data of yellow, cyan and magenta

On the other hand, in the case of the matrix calculation method, for example, for obtaining printing data of Y, M and C from image data of R, G and B, the following formula (11) is used as a basic calculation formula.

$$\begin{bmatrix} Y \\ M \\ C \end{bmatrix} = (Aij) \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad \dots (11)$$

Here, A_{ij} represents coefficients, with $i = 1$ to 3 , and $j = 1$ to 3 .

However, by the simple linear calculation of the formula (11), it is impossible to provide a good conversion characteristic because of a non-linearity of an image-printing or the like.

A method has been proposed for providing a conversion characteristic to improve the foregoing characteristic. This method is disclosed in Japanese Patent Application Kokoku Publication H2-30226, directed to a color correction calculation device, and employs a matrix calculation formula

(12) below.

$$\begin{bmatrix} Y \\ M \\ C \end{bmatrix} = (D_{ij}) \begin{bmatrix} R \\ G \\ B \\ R \cdot G \\ G \cdot B \\ B \cdot R \\ R \cdot R \\ G \cdot G \\ B \cdot B \\ N \end{bmatrix} \quad \dots (12)$$

Here, N is a constant, $i = 1$ to 3, and $j = 1$ to 10.

In the foregoing formula (12), since image data having a mixture of an achromatic component and a color component is directly used, mutual interference occur in computation. In other words, if one of the coefficients is changed, influence is given to the components or hues other than the target component or hue (the component or hue for which the coefficient is changed). Consequently, a good conversion characteristic cannot be realized.

A color conversion method disclosed in Japanese Patent Application Kokai Publication H7-170404 is a proposed solution to this problem. Fig. 20 is a block circuit diagram showing the color conversion method for conversion of image data of R, G and B into printing data of C, M and Y, disclosed in Japanese Patent Application Kokai Publication H7-170404. In the drawing, reference numeral 100 denotes a complement calculator; 101, a minimum and maximum calculator; 102, a hue data calculator; 103, a polynomial calculator; 104, a matrix calculator; 105, a coefficient generator; and 106, a synthesizer.

Next, the operation will be described. The complement calculator 100 receives image data R, G and B, and outputs complementary color data C_i , M_i and Y_i which have been obtained by determining 1's complements.

The determination of 1's complement of an input data can be achieved by subtracting the value of the input data of n bits (n being an integer) from $(2^n - 1)$. For example, in the case of 8-bit data, the value of the input data is deducted from "255".

The minimum and maximum calculator 101 outputs a maximum value β and a minimum value α of this complementary color data and an identification code S for indicating, among the six hue data, data which are zero.

The hue data calculator 102 receives the complementary color data C_i , M_i and Y_i and the maximum and minimum values β and α , and outputs six hue data r , g , b , y , m and c which are obtained by executing the following subtraction:

$$\begin{aligned} r &= \beta - C_i, \\ g &= \beta - M_i, \\ b &= \beta - Y_i, \\ y &= Y_i - \alpha, \\ m &= M_i - \alpha, \text{ and} \\ c &= C_i - \alpha. \end{aligned}$$

Here, among the six hue data, at least two assume the value zero.

The polynomial calculator 103 receives the hue data and the identification code S , selects, from r , g and b , two data Q_1 and Q_2 which are not zero and, from y , m and c , two data P_1 and P_2 which are not zero. Based on these data, the polynomial calculator 103 computes polynomial data:

$$\begin{aligned} T_1 &= P_1 * P_2, \\ T_3 &= Q_1 * Q_2, \\ T_2 &= T_1 / (P_1 + P_2), \text{ and} \\ T_4 &= T_3 / (Q_1 + Q_2), \end{aligned}$$

and then outputs the results of the calculation.

It is noted that asterisks "*" are sometimes used in this specification to indicate multiplication.

The coefficient generator 105 generates calculation

coefficients $U(F_{ij})$ and fixed coefficients $U(E_{ij})$ for the polynomial data based on information of the identification code S. The matrix calculator 104 receives the hue data y , m and c , the polynomial data $T1$ to $T4$ and the coefficients U , and outputs the result of the following formula (13) as color ink data $C1$, $M1$ and $Y1$.

$$\begin{bmatrix} C1 \\ M1 \\ Y1 \end{bmatrix} = (E_{ij}) \begin{bmatrix} c \\ m \\ y \end{bmatrix} + (F_{ij}) \begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ c*m/(c+m) \\ m*y/(m+y) \\ y*c/(y+c) \\ r*g/(r+g) \\ g*b/(g+b) \\ b*r/(b+r) \end{bmatrix} \quad \dots(13)$$

The synthesizer 106 adds together the color ink data $C1$, $M1$ and $Y1$ and data α which is the achromatic data, and outputs printing data C , M and Y . Accordingly, the following formula (14) is used for obtaining printing data.

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = (E_{ij}) \begin{bmatrix} c \\ m \\ y \end{bmatrix} + (F_{ij}) \begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ c*m/(c+m) \\ m*y/(m+y) \\ y*c/(y+c) \\ r*g/(r+g) \\ g*b/(g+b) \\ b*r/(b+r) \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \quad \dots(14)$$

The formula (14) shows a general formula for a group of pixels.

Fig. 21A to Fig. 21F, which are schematic diagrams, show relations between six hues of red (R), green (G), blue

Fig. 22A to Fig. 22F, which are schematic diagrams, show relations between the six hues and product terms $y \cdot m$, $r \cdot g$, $c \cdot y$, $g \cdot b$, $m \cdot c$ and $b \cdot r$.

Also, each of the six fraction terms $y*m/(y + m)$, $m*c/(m + c)$, $c*y/(c + y)$, $r*g/(r + g)$, $g*b/(g + b)$ and $b*r/(b + r)$ in the formula (14) relates to only one hue among the six hues.

As apparent from the foregoing, according to the color conversion method shown in Fig. 20, by changing coefficients for the product terms and the fraction terms regarding the specific hue, only the target hue can be adjusted without influencing other hues.

Each of the foregoing product terms is determined by a second-order computation for chroma, and each of the fraction terms is determined by a first-order computation for chroma. Thus, by using both of the product terms and the fraction terms, the non-linearity of an image-printing for chroma can be adjusted.

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conventional color conversion method of the matrix computation type could not meet such a desire.

The problems of the conventional color conversion method or color conversion device are summarized as follows. Where the color conversion device is of a three-dimensional look-up table conversion method employing a memory such as ROM, a large-capacity memory is required, and a conversion characteristic cannot be flexibly changed. Where the color conversion device is of a type using a matrix calculation method, although it is possible to change only a target hue, it is not possible to vary the color in the inter-hue areas between adjacent ones of the six hues of red, blue, green, yellow, cyan and magenta, and good conversion characteristics cannot be realized throughout the entire color space. Moreover, with the matrix conversion method shown in Fig. 20, when the output of the output device represented by the reflectivity or luminance, or the like has a non-linear gray scale characteristics with respect to the image data, as in the case of a printing device, a cathode-ray tube display device, liquid crystal display device, or the like, desirable conversion characteristics cannot be obtained.

SUMMARY OF THE INVENTION

The present invention was made to solve the foregoing problems.

An object of the present invention is to provide a color conversion device and a color conversion method for performing color-conversion wherein independent adjustment is performed not only for six hues of red, blue, green, yellow, cyan and magenta but also six inter-hue areas of red-yellow, yellow-green, green-cyan, cyan-blue, blue-magenta and magenta-red, and a conversion characteristic can be flexibly changed, and a good conversion can be achieved

even when an output device has a non-linear characteristics, and no large-capacity memories, such as three-dimensional look-up tables, are necessary.

According to a first aspect of the invention, there is provided a color conversion device for performing pixel-by-pixel color conversion from a first set of three color data representing red, green and blue, or cyan, magenta and yellow, into a second set of three color data representing red, green and blue, or cyan, magenta, and yellow, said device comprising:

first calculation means for calculating a minimum value α and a maximum value β of said first set of three color data for each pixel;

hue data calculating means for calculating hue data r, g, b, y, m and c based on said first set of three color data, and said minimum and maximum values α and β outputted from said calculating means;

means for generating first comparison-result data based on the hue data outputted from said hue data calculating means;

means for generating second comparison-result data based on said first comparison-result data;

second calculation means for performing calculation using the hue data outputted from said hue data calculating means to produce calculation result data;

coefficient generating means for generating specified matrix coefficients for the hue data, the calculation result data, the first comparison-result data and the second comparison-result data;

third calculation means responsive to said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, and the coefficients from said coefficient generating means for calculating a third set of three color data representing

red, green and blue, or cyan, magenta, and yellow, said third calculation means performing calculation including matrix calculation performed at least on said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, and the coefficients from said coefficient generating means; and

gray scale conversion means for converting the gray scale of said third set of three color data, to produce said second set of three color data.

Since the second set of three color data is obtained by gray scale conversion of the third set of three color data, the second set are of the same combination of colors as the third set. That is, if the third set comprises red, green and blue, the second set also comprises red, green and blue. If the third set comprises cyan, magenta and yellow, the second set also comprises cyan, magenta and yellow.

With the above arrangement, it is possible to independently vary not only the colors of the six hues of red, blue, green, yellow, cyan and magenta, but also the colors in the six inter-hue areas of red-yellow, yellow-green, green-cyan, cyan-blue, blue-magenta, and magenta-red. Moreover, by performing the gray scale conversion by means of the gray scale conversion means, it is possible to compensate for third-order or higher-order non-linearities, or complicated, non-linear characteristics (e.g., S-shaped characteristics) such as the one which liquid-crystal displays exhibit, and which cannot be obtained just by combining the first-order and second-order calculations. Accordingly, it is possible to obtain color conversion methods or color conversion devices which can change the conversion characteristics flexibly, without requiring a large-capacity memory. It is noted that the gray scale conversion means can be realized by a one-dimensional look-up table, and its size is much smaller than the three-

dimensional look-up table.

Moreover, because the second comparison-result data calculated from the first comparison-result data are used as calculation term relating to the inter-hue areas in the matrix calculation, the number of calculation steps required can be reduced than if they are calculated from the hue data r , g , b , y , m , c .

It may be so configured that

said third calculation means performs said matrix calculation on said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, and the coefficients from said coefficient generating means, and further includes synthesizing means for adding said minimum value α from said first calculation means to the results of said matrix calculation.

It may be so configured that

said coefficient generating means generates predetermined matrix coefficients E_{ij} ($i = 1$ to 3 , $j = 1$ to 3), and F_{ij} ($i = 1$ to 3 , $j = 1$ to 18), and

said third calculation means performs the calculation using the hue data, said said first comparison-result data, said second comparison-result data, said calculation result data, said minimum value α from said calculating means, and said matrix coefficients to determine the third set of three color data representing red, green and blue, denoted by R_o , G_o and B_o , in accordance with the following formula (1):

$$\begin{bmatrix} \text{Ro} \\ \text{Go} \\ \text{Bo} \end{bmatrix} = (\text{Eij}) \begin{bmatrix} \text{r} \\ \text{g} \\ \text{b} \end{bmatrix} + (\text{Fij}) \begin{bmatrix} \text{h1b} \\ \text{h1c} \\ \text{h1m} \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \quad \dots (1)$$

It may be so configured that
said coefficient generating means generates
predetermined matrix coefficients E_{ij} ($i = 1$ to 3 , $j = 1$ to
 3), and F_{ij} ($i = 1$ to 3 , $j = 1$ to 18), and

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$$\begin{bmatrix} \text{Co} \\ \text{Mo} \\ \text{Yo} \end{bmatrix} = (\text{Eij}) \begin{bmatrix} \text{c} \\ \text{m} \\ \text{y} \end{bmatrix} + (\text{Fij}) \begin{bmatrix} \text{h1b} \\ \text{h1c} \\ \text{h1m} \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \quad \dots (2)$$

It may be so configured that said third calculation means performs said matrix calculation on said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, the coefficients from said coefficient generating means, and said minimum value α from said first calculation means.

said coefficient generating means generates predetermined matrix coefficients E_{ij} ($i = 1$ to 3 , $j = 1$ to 3), and F_{ij} ($i = 1$ to 3 , $j = 1$ to 19), and

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$$\begin{bmatrix} Ro \\ Go \\ Bo \end{bmatrix} = (E_{ij}) \begin{bmatrix} r \\ g \\ b \end{bmatrix} + (F_{ij}) \begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \\ \alpha \end{bmatrix} \quad \dots (3)$$

wherein h1r, h1g, h1b, h1c, h1m and h1y denote said first comparison-result data, and h2ry, h2rm, h2gy, h2gc, h2bm and h2bc denote said second comparison result data.

It may be so configured that

said coefficient generating means generates predetermined matrix coefficients E_{ij} ($i = 1$ to 3 , $j = 1$ to 3), and F_{ij} ($i = 1$ to 3 , $j = 1$ to 19), and

said third calculation means performs the calculation using the hue data, said said first comparison-result data, said second comparison-result data, said calculation result data, said minimum value α from said calculating means, and said matrix coefficients to determine the third set of three color data representing cyan, magenta and yellow denoted by Co , Mo and Yo , in accordance with the following formula (4):

. . . (4)

and blue,

said third set of three color data represent cyan, magenta and yellow,

said device further comprises means for determining complement of said first set of three color data, and

said hue data calculation means calculates the hue data r , g , b , y , m , c by subtraction in accordance with:

$$r = \beta - C_i,$$

$$g = \beta - M_i,$$

$$b = \beta - Y_i,$$

$$y = Y_i - \alpha,$$

$$m = M_i - \alpha, \text{ and}$$

$$c = C_i - \alpha,$$

wherein C_i , M_i and Y_i represent data produced by the determination of the complement of said first set of three color data.

With the above arrangement, the hue data calculating means can be configured of means for performing subtraction based on the input image of red, green and blue, or cyan, magenta and yellow and the maximum value β and minimum value α from the first calculation means.

It may be so configured that

said first comparison-result data generating means determines the comparison-result data among the hue data r , g and b , and the comparison-result data among the hue data y , m and c , and

said second comparison-result data generating means comprises multiplying means for multiplying the first comparison-result data outputted from said first comparison-result data generating means with specific calculation coefficients, and means for determining the comparison-result data based on the outputs of said multiplication means.

With the above arrangement, the first comparison-result

data generating means and the second comparison-result data generating means are configured of means for performing comparison, and means for performing multiplication.

It may be so configured that

said first comparison-result data generating means determines the first comparison-result data:

h1r = min (m, y),
h1g = min (y, c),
h1b = min (c, m),
h1c = min (g, b),
h1m = min (b, r), and
h1y = min (r, g),

(with min (A, B) representing the minimum value of A and B),

said second comparison-result data generating means determines the second comparison-result data:

h2ry = min (aq1*h1y, ap1*h1r),
h2rm = min (aq2*h1m, ap2*h1r),
h2gy = min (aq3*h1y, ap3*h1g),
h2gc = min (aq4*h1c, ap4*h1g),
h2bm = min (aq5*h1m, ap5*h1b), and
h2bc = min (aq6*h1c, ap6*h1m).

With the above arrangement, the first comparison-result data generating means can be configured of means for performing minimum value selection, and the second comparison-result data can be configured of means for performing multiplication and means for performing minimum value selection.

It may be so configured that said multiplying means in said second comparison-result data generating means performs calculation on said first comparison result-data and said calculation coefficients by setting said calculation coefficients aq1 to aq6 and ap1 to ap6 to integral values of 2^n , with n being an integer, and by bit shifting.

With the above arrangement, the multiplication can be

zero, and other coefficients are set to specified values.

With the above arrangement, it is not necessary to calculate the product terms for which the coefficients are zero, and yet it is possible to linearly adjust only the target hue or inter-hue area (among the six hues of red, blue, green, yellow, cyan and magenta, and the six inter-hue areas) without influencing other hues or inter-hue areas.

It may be so configured that

said first calculation means calculates a maximum value β and a minimum value α using said first set of three color data, and generates an identification code indicating the hue data which is of a value zero, and

said second calculation means performs arithmetic operation on said hue data based on the identification code outputted from said first calculation means,

said coefficient generating means generates said matrix coefficients based on the identification code outputted from said first calculation means, and

said third calculation means performs matrix calculation using the coefficient from said coefficient generating means to produce the third set of three color data based on the identification code outputted from said first calculation means.

With the above arrangement, the number of steps for performing the matrix calculation can be reduced.

According to another aspect of the invention, there is provided a color conversion method of performing pixel-by-pixel color conversion from a first set of three color data representing red, green and blue, or cyan, magenta and yellow, into a second set of three color data representing red, green and blue, or cyan, magenta, and yellow, said method comprising the steps of:

(a) calculating a minimum value α and a maximum value β of said first set of three color data for each pixel;

Said step (g) may alternatively comprise the step of

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing an example of configuration of a color conversion device of Embodiment 1 of the present invention:

Fig. 3 is a table showing an example of the relationship between an identification code S1, and the maximum and minimum values β and α , and hue data whose value is zero, in the color conversion device of Embodiment 1;

Fig. 4 is a table showing the operation of a zero remover of the polynomial calculator in the color conversion device of Embodiment 1:

Fig. 5 is a block diagram showing an example of configuration of a matrix calculator included in the color conversion device of Embodiment 1;

Fig. 6A to Fig. 6F are diagrams schematically showing the relationship between six six hues and hue data;

Fig. 7A to Fig. 7F are diagrams schematically showing the relationship between six hues and product terms in the color conversion device of Embodiment 1;

Fig. 8A to Fig. 8F are diagrams schematically showing the relationship between six hues and first comparison-result data in the color conversion device of Embodiment 1;

Fig. 9A to Fig. 9F are diagrams schematically showing

the relationship between six inter-hue areas and second comparison-result data in the color conversion device of Embodiment 1;

Fig. 10A to Fig. 10F are diagrams schematically showing how the range of each inter-hue area is changed with the change of the coefficients multiplied at the polynomial calculator is changed;

Fig. 11A and Fig. 11B are tables showing the relationship between respective hues or inter-hue areas, and effective calculation terms or data which relate to and are effective for each hue or inter-hue area;

Fig. 12 is an xy chromaticity diagram illustrating the gamut of the color reproduction of the input color signals and the gamut of a desired color reproduction, for explaining the operation of Embodiment 1;

Fig. 13 is an xy chromaticity diagram illustrating the gamut of the color reproduction obtained by adjusting the coefficients for the first comparison-result data, together with the gamut of the desired color reproduction, for explaining the operation of Embodiment 1;

Fig. 14 is an xy chromaticity diagram for explaining the gamut of the color reproduction obtained by adjusting the coefficients for the first and second comparison-result data, together with the gamut of the desired color reproduction, for explaining the operation of Embodiment 1;

Fig. 15 is a block diagram showing an example of configuration of a color conversion device of Embodiment 2 of the present invention;

Fig. 16 is a block diagram showing an example of configuration of Embodiment 3 of the present invention;

Fig. 17 is a block diagram showing part of an example of configuration of a matrix calculator included in the color conversion device of Embodiment 3;

Fig. 18 is a block diagram showing an example of

Fig. 22A to Fig. 22F are diagrams schematically showing the relationship between six hues and calculation terms in a matrix calculator included in the conventional color conversion device.

Next, the preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings.

Fig. 1 is a block diagram showing an example of configuration of a color conversion device of Embodiment 1 of the present invention. The illustrated color conversion device is for converting a first set of three color data representing red, green and blue, denoted by R_i , G_i and B_i , into a second set of three color data, also representing red, green and blue, denoted by R_p , G_p and B_p . A minimum and maximum calculator 1 calculates a maximum value β and a minimum value α of the inputted first set of three colors, also called image data R_i , G_i and B_i , and generates and outputs an identification code S_1 for indicating, among the six hue data, data which are zero, as will be better understood from the following description. A hue data

calculator 2 calculates hue data r , g , b , y , m and c from the image data R_i , G_i and B_i and the outputs from the minimum and maximum calculator 1. The color conversion device further comprises a polynomial calculator 3, a matrix calculator 4, a coefficient generator 5, and a synthesizer 6. The synthesizer 6 outputs a third set of three color data, denoted by R_o , G_o and B_o .

A gray scale converters 15a, 15b and 15c respectively convert the gray scale, i.e., tone of the third set of three color data, R_o , G_o and B_o , and output the second set of image data R_p , G_p and B_p .

Fig. 2 is a block diagram showing an example of configuration of the polynomial calculator 3. In Fig. 2, a zero remover 7 removes, from the inputted hue data, data which are of value zero. Reference numerals 8a and 8b denote multipliers. Minimum selectors 9a, 9b and 9c select and output the minimum of the input data. A calculation coefficient generator 11 generates and outputs calculation coefficients based on the identification code S_1 from the minimum and maximum calculator 1. Arithmetic units 10a and 10b perform multiplication between the calculation coefficients represented by the outputs of the calculation coefficient generator 11 and the outputs from the minimum selectors 9a and 9b.

Next, the operation will be described. The inputted image data R_i , G_i and B_i corresponding to the three colors of red, green and blue are sent to the minimum and maximum calculator 1 and the hue data calculator 2. The minimum and maximum calculator 1 calculates and outputs a maximum value β and a minimum value α of the inputted image data R_i , G_i and B_i , and also generates and outputs an identification code S_1 for indicating, among the six hue data, data data which are zero.

The hue data calculator 2 receives the inputted image

$$\begin{aligned} r &= R_i - \alpha, \\ g &= G_i - \alpha, \\ b &= B_i - \alpha, \\ y &= \beta - B_i, \\ m &= \beta - G_i, \text{ and} \\ c &= \beta - R_i, \end{aligned}$$

The maximum and minimum values β and α calculated by the minimum and maximum calculator 1 are respectively represented as follows:

Since the six hue data r, g, b, y, m and c calculated by the hue data calculator 2 are obtained by the subtraction of

at least two among these six hue data are of a value zero. For example, if a maximum value β is R_i and a minimum value α is G_i ($\beta = R_i$, and $\alpha = G_i$), $g = 0$ and $c = 0$. If a maximum value β is R_i and a minimum value α is B_i ($\beta = R_i$, and $\alpha = B_i$), $b = 0$ and $c = 0$. In other words, in accordance with a combination of R_i , G_i and B_i which are the largest and the smallest, respectively, one of r , g and b , and one of y , m and c , i. e., in total two of them have a value zero.

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Then, the six hue data r, g, b, y, m and c outputted from the hue data calculator 2 are sent to the polynomial calculator 3, and the hue data r, g and b are also sent to the matrix calculator 4. The polynomial calculator 3 also receives the identification code S1 outputted from the minimum and maximum calculator 1, and performs calculation by selecting, from the hue data r, g and b, two data Q1 and Q2 which are not of a value zero, and from the hue data y, m and c, two data P1 and P2 which are not of a value zero. Next, this operation will be described by referring to Fig. 2.

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Fig. 4 represent just an example, and may be other than those shown in Fig. 4.

The data Q1 and Q2 outputted from the zero remover 7 are inputted to the multiplier 8a, which calculates and outputs the product $T3 = Q1 \cdot Q2$. The data P1 and P2 outputted from the zero remover 7 are inputted to the multiplier 8b, which calculates and outputs the product $T1 = P1 \cdot P2$.

The minimum selector 9a selects and outputs the minimum value $T4 = \min(Q1, Q2)$ among the output data Q1 and Q2 from the zero remover 7. The minimum selector 9b selects and outputs the minimum value $T2 = \min(P1, P2)$ among the output data P1 and P2 from the zero remover 7. The outputs of the minimum selectors 9a and 9b are the first comparison-result data.

The identification code S1 is inputted from the minimum and maximum calculator 1 to the calculation coefficient generator 11, which generates signals indicating calculation coefficients aq and ap based on the identification code S1, and the coefficient aq is supplied to the arithmetic unit 10a, and the coefficient ap is supplied to the arithmetic unit 10b. These calculation coefficients aq and ap are used for multiplication with the comparison-result data T4 and T2, and each of the calculation coefficients aq and ap can assume one of the six values, corresponding to the value of the identification code S1 shown in Fig. 4. The arithmetic unit 10a receives the comparison-result data T4 from the minimum selector 9a, performs multiplication of $aq \cdot T4$, and sends the result to the minimum selector 9c. The arithmetic unit 10b receives the comparison-result data T2 from the minimum selector 7, performs multiplication of $ap \cdot T2$, and sends the result to the minimum selector 9c.

The minimum selector 9c selects and outputs the minimum value $T5 = \min(aq \cdot T2, ap \cdot T4)$ of the outputs the arithmetic

units 10a and 10b. The output of the minimum value selector 9c is a second comparison-result data.

The polynomial data T1, T2, T3, T4 and T5 outputted from the polynomial calculator 3 are supplied to the matrix calculator 4.

The coefficient generator 5 shown in Fig. 1 generates calculation coefficients U (Fij) and fixed coefficients U (Eij) for the polynomial data based on the identification code S1, and sends the same to the matrix calculator 4.

The matrix calculator 4 receives the hue data r, g and b from the hue data calculator 2, the polynomial data T1 to T5 from the polynomial calculator 3 and the coefficients U from the coefficient generator 5, and outputs the results of calculation according to the following formula (6) as image data R1, G1 and B1.

$$\begin{bmatrix} R1 \\ G1 \\ B1 \end{bmatrix} = (Eij) \begin{bmatrix} r \\ g \\ b \end{bmatrix} + (Fij) \begin{bmatrix} T1 \\ T2 \\ T3 \\ T4 \\ T5 \end{bmatrix} \quad \dots(6)$$

For (Eij), i = 1 to 3 and j = 1 to 3, and for (Fij), i = 1 to 3 and j = 1 to 5.

Fig. 5, which is a block diagram, shows an example of configuration of part of the matrix calculator 4. Specifically, it shows how R1 is calculated and outputted. As shown in Fig. 5, the matrix calculator 4 includes multipliers 12a to 12f, and adders 13a to 13e interconnected as illustrated.

Next, the operation of the matrix calculator 4 of Fig. 5 will be described. The multipliers 12a to 12f receive the hue data r, the polynomial data T1 to T5 from the polynomial calculator 3 and the coefficients U (Eij) and U (Fij) from the coefficient generator 5, and then output the products thereof. The adders 13a and 13b receive the products

Where it is desired to increase the calculation speed of the color conversion method or the color conversion device of this embodiment, since parts of the coefficients (E_{ij}) and (F_{ij}) which respectively correspond to the hue data r , g and b are used, the configurations each as shown in Fig. 5 may be used in parallel, so as to perform the matrix calculation at a higher speed.

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$$\begin{bmatrix} \text{Ro} \\ \text{Go} \\ \text{Bo} \end{bmatrix} = (\text{Eij}) \begin{bmatrix} \text{r} \\ \text{g} \\ \text{b} \end{bmatrix} + (\text{Fij}) \begin{bmatrix} \text{h1g} \\ \text{h1b} \\ \text{h1c} \\ \text{h1m} \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \quad \dots (1)$$

```

h1r = min (m, y),
h1g = min (y, c),
h1b = min (c, m),
h1c = min (g, b),
h1m = min (b, r),
h1y = min (r, g),
h2ry = min (aq1*h1y, ap1*h1r),
h2rm = min (aq2*h1m, ap2*h1r),
h2gy = min (aq3*h1y, ap3*h1g),
h2gc = min (aq4*h1c, ap4*h1g),
h2bm = min (aq5*h1m, ap5*h1b), and
h2bc = min (aq6*h1c, ap6*h1b),

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The difference between the number of calculation terms in the formula (1) and the number of calculation terms in Fig. 1 is that Fig. 1 shows a method of calculation for each

pixel excluding the calculation terms which are of a value zero, while the formula (1) represents a general formula for a set of pixels. In other words, eighteen polynomial data for one pixel of the formula (1) can be reduced to five effective data, and this reduction is achieved by exploiting a characteristic of the hue data.

The combination of effective data is changed according to image data of the target pixel. For all image data, all the polynomial data can be effective.

Fig. 6A to Fig. 6F schematically show relations between the six hues (red, yellow, green, cyan, blue, magenta) and the hue data y, m, c, r, g and b. Each hue data relates to, i.e., extends to cover the range of three hues. For example, y as shown in Fig. 6A relates to, or extends to cover three hues of red, yellow and green.

Fig. 7A to Fig. 7F schematically show relations between the six hues and the product terms $y*m$, $r*g$, $c*y$, $g*b$, $m*c$ and $b*r$, and it can be understood that each product term is a second-order term for a specified hue. For example, if W is a constant, since $r = W$ and $g = b = 0$ hold for red, $y = m = W$ and $c = 0$ are obtained. Accordingly, $y*m = W*W$ is realized, and this term is a second-order term. The other five terms are all zero. In other words, only $y*m$ is an effective second-order term for red. Similarly, $c*y$ is the only effective term for green; $m*c$ for blue; $g*b$ for cyan; $b*r$ for magenta; and $r*g$ for yellow.

Each of the foregoing formulae (6) and (1) includes a first comparison-result data effective only for one hue.

The first comparison-result data are:

$h1r = \min (y, m),$
 $h1y = \min (r, g)$
 $h1g = \min (c, y),$
 $h1c = \min (g, b),$
 $h1b = \min (m, c),$ and

$$h_{lm} = \min(b, r).$$

Fig. 8A to Fig. 8F schematically show relations between the six hues and first comparison-result data h_{lr} , h_{ly} , h_{lg} , h_{lc} , h_{lb} , and h_{lm} . It is seen that each of the first comparison-result data relates to only one specific hue.

The six first comparison-result data has the nature of a first-order term. For instance, if W is a constant, for red, $r = W$, $g = b = 0$, so that $y = m = W$, and $c = 0$. As a result, $\min(y, m) = W$ has a first-order value. The other five first comparison-result data are all of a value zero. That is, for red, $h_{lr} = \min(y, m)$ alone is the only effective first comparison-result data. Similarly, $h_{lg} = \min(c, y)$ is the only effective first comparison-result data for green; $h_{lb} = \min(m, c)$ for blue; $h_{lc} = \min(g, b)$ for cyan; $h_{lm} = \min(b, r)$ for magenta; and $h_{ly} = \min(r, g)$ for yellow.

Next, a difference between the first-order and second-order terms will be described. As described above, for red, if W is a constant, $y \cdot m = W \cdot W$ is realized, and the other product terms are all zero. Here, since the constant W indicates the magnitudes of the hue signals y and m , the magnitude of the constant W depends on the color brightness or chroma. With $y \cdot m = W \cdot W$, the product term $y \cdot m$ is a second-order function for chroma. The other product terms are also second-order functions for chroma regarding the hues to which these terms are effective. Accordingly, influence given by each product term to color reproduction is increased in a second-order manner as chroma is increased. In other words, the product term is a second-order term which serves as a second-order adjustment term for chroma in color reproduction.

On the other hand, for red, if W is a constant, $h_{lr} = \min(m, m) = W$ is realized, and the other first comparison-result data are all zero. Here, the magnitude of the

constant W depends of color brightness or chroma. With $h1r = \min(y, m) = W$, the comparison-result data $h1r = \min(y, m)$ is a first-order function for chroma. The other first comparison-result data are also first-order functions for chroma regarding the hues to which these terms are effective. Accordingly, the influence given by each first comparison-result data to color reproduction is a first-order function for chroma. In other words, the first comparison-result data is a first-order term which serves as a first-order adjustment term for chroma in color reproduction.

Fig. 9A to Fig. 9F schematically show relations between the six hues and second comparison-result data:

$$\begin{aligned} h2ry &= \min(h1y, h1r), \\ h2gy &= \min(h1y, h1g), \\ h2gc &= \min(h1c, h1g), \\ h2bc &= \min(h1c, h1b), \\ h2bm &= \min(h1m, h1b), \text{ and} \\ h2rm &= \min(h1m, h1r). \end{aligned}$$

This is the case in which the coefficients $aq1$ to $aq6$ and $ap1$ to $ap6$ in

$$\begin{aligned} h2ry &= \min(aq1 \cdot h1y, ap1 \cdot h1r), \\ h2rm &= \min(aq2 \cdot h1m, ap2 \cdot h1r), \\ h2gy &= \min(aq3 \cdot h1y, ap3 \cdot h1g), \\ h2gc &= \min(aq4 \cdot h1c, ap4 \cdot h1g), \\ h2bm &= \min(aq5 \cdot h1m, ap5 \cdot h1b), \text{ and} \\ h2bc &= \min(aq6 \cdot h1c, ap6 \cdot h1b), \end{aligned}$$

in the formula (1) above are all of a value "1".

It can be understood from Fig. 9A to Fig. 9F, that each of the second comparison-result data relates to changes in the six inter-hue areas of red-green, yellow-green, green-cyan, cyan-blue, blue-magenta, and magenta-red. In other words, for red-yellow, $b = c = 0$, and the five terms other than $h2ry = \min(h1y, h1r) = \min(\min(r, g), \min(y, m))$

Moreover, the range of the inter-hue area to which each of the second comparison-result data relates is half that of the range of the hue to which each of the first comparison-result data relates.

Specifically, for inter-hue area red-yellow, only $h2ry = \min(aq1 \cdot h1y, ap1 \cdot h1r)$ is an effective second comparison-result data. If, for example, the ratio between $aq1$ and $ap1$ is 2:1, the peak value of the second comparison-result data is shifted toward red, as indicated by the broken line $a1$ in Fig. 10A; and thus it can be made an effective comparison-result data for an area closer to red in the inter-hue area of red-yellow. On the other hand, for example if the ratio between $aq1$ and $ap1$ is 1:2, the relationship is like that indicated by the broken line $b1$ in Fig. 10A, the peak value of the second comparison-result data is shifted toward yellow, and thus it can be made an effective comparison-result data for an area closer to yellow in the inter-hue area of red-yellow. Similarly, by respectively changing: $aq3$ and $ap3$ in $h2gy$ for yellow-green.

Fig. 11A and Fig. 11B respectively show relations between the six hues and inter-hue areas and effective calculation terms. Thus, if the coefficient generator 5 changes coefficients for a calculation term effective for a hue or an inter-hue area to be adjusted, only the target hue or inter-hue area can be adjusted. Further, if coefficients generated by the calculation coefficient generator 11 in the polynomial calculator 3 are changed, part of the inter-hue area where a calculation term in the inter-hue area is most effective can be changed without giving any influence to the other hues.

Next, an example of coefficients generated by the coefficient generator 5 of Embodiment 1 described above with reference to Fig. 1 will be described. The following formula (5) shows an example of coefficients $U(E_{ij})$ generated by the coefficient generator 5.

$$(E1j) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \dots (5)$$

If the coefficients $U(F_{ij})$ in the foregoing formula are all zero this represents the case where color conversion is not executed. The following formula (7) shows the case where, of the coefficients $U(F_{ij})$, the coefficients for second-order calculation terms which are product terms are all zero, and coefficients for first comparison-result data and second comparison-result data, both of which are first-order calculation terms, are represented by, for example Ar_1

to Ar3, Ay1 to Ay3, Ag1 to Ag3, Ac1 to Ac3, Ab1 to Ab3, Am1 to Am3, Ary1 to Ary3, Agy1 to Agy3, Agc1 to Agc3, Abc1 to Abc3, Abm1 to Abm3 and Arm1 to Arm3.

(Fij)

$$= \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & Ar1 & Ag1 & Ab1 & Ac1 & Am1 & Ay1 & Ary1 & Arm1 & Agy1 & Agc1 & Abm1 & Abc1 \\ 0 & 0 & 0 & 0 & 0 & 0 & Ar2 & Ag2 & Ab2 & Ac2 & Am2 & Ay2 & Ary2 & Arm2 & Agy2 & Agc2 & Abm2 & Abc2 \\ 0 & 0 & 0 & 0 & 0 & 0 & Ar3 & Ag3 & Ab3 & Ac3 & Am3 & Ay3 & Ary3 & Arm3 & Agy3 & Agc3 & Abm3 & Abc3 \end{bmatrix} \dots(7)$$

In the foregoing, adjustment is performed by using the first comparison-result data and second comparison-result data, both of which are first-order calculation terms. Accordingly, only a hue or an inter-hue area can be linearly adjusted. If coefficients relating to the first-order calculation term for a hue or an inter-hue area to be adjusted are set to values other than zero, and the other coefficients are made to be zero, only the target hue or inter-hue area can be adjusted. For example, if coefficients Ar1 to Ar3 relating to h1r relating to red are set, the red hue is changed, and to vary the colors in the red-to-yellow inter-hue area, the coefficients Ary1 to Ary3 relating to h2ry are used.

Where it is intended to make only linear adjustment of the hues and inter-hue areas, it is not necessary to calculate the product terms. In this case, the multipliers 8a and 8b in the polynomial calculator 3 shown in Fig. 2, and the multipliers 12b and 12d, and the adders 13a and 13b in the matrix calculator 4 shown in Fig. 5 may be omitted. In this case, the non-linear characteristics taking into consideration the characteristics of the output device may be realized by the use of the gray scale converters 15a, 15b and 15c.

Furthermore, if, in the polynomial calculator 3, the values of calculation coefficients aq1 to aq6 and ap1 to ap6

in

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h2ry = min (aq1*hly, ap1*hlr),
h2rm = min (aq2*hlm, ap2*hlr),
h2gy = min (aq3*hly, ap3*hlg),
h2gc = min (aq4*hlc, ap4*hlg),
h2bm = min (aq5*hlm, ap5*hlb), and
h2bc = min (aq6*hlc, ap6*hlb)

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are changed so as to assume integral values of 1, 2, 4, 8, ..., i.e., 2^n (where n is an integer), multiplication can be achieved in the arithmetic units 10a and 10b by bit shifting.

As apparent from the foregoing, by changing the coefficients for the product terms and first comparison-result data relating to specific hues, it is possible to adjust only the target hue among the six hues of red, blue, green, yellow, cyan and magenta, and by changing the coefficients for the second comparison-result data, it is possible to vary the colors in the six inter-hue areas of red-yellow, yellow-green, green-cyan, cyan-blue, blue-magenta, and magenta-red. The adjustment of each hue or inter-hue area can be achieved independently, i.e., without influencing other hues or other inter-hue areas.

Each of the foregoing product terms is a second-order calculation for chroma, and each of the first and second comparison-result data is a first-order calculation for chroma. Accordingly, by using the product terms, and the first and second comparison-result data, the non-linearity of an image printing or the like can be varied for chroma.

The image data R_o , G_o and B_o outputted by the synthesizer 6 are inputted the gray scale converters 15a, 15b and 15c, where gray scale correction is applied.

By performing the gray scale conversion at the gray scale converters 15a, 15b and 15c, it is possible to compensate for third-order or higher-order non-linearities,

The gray scale converters 15a, 15b and 15c may be in the form of a one-dimensional look-up table, or a calculation means having the input-output characteristics of a power function.

Further description on the operation of the color conversion device using the coefficients represented by the formulae (5) and (7) will be given. Fig. 12 to Fig. 14 show an xy chromaticity diagram showing the operation of the color conversion device of Embodiment 1. In Fig. 12 to Fig. 14, the dotted line 21 represents the gamut of the desired color reproduction. In Fig. 12, the triangle of the solid line 22 represents the gamut of color reproduction (reproducible colors) of the input color signals R_i , G_i and B_i . Here, the input color signals may be those for a certain type of image reproducing device, such as a display device, e.g., a CRT monitor. The "desired color reproduction" may be the color reproduction by another type of display device, or theoretical or imaginary color reproduction.

In the example of Fig. 12, there are differences

The color conversion device of Embodiment 1 of the invention uses the first comparison-result data effective for each of the six hues, and the second comparison-result data effective for each of the inter-hue areas.

Fig. 14 shows the gamut 25 of the color reproduction obtained when both the coefficients for the first comparison-result data and the coefficients for the second comparison-result data are adjusted. By adjusting both the coefficients for the first and second comparison-result data, the hues of the color reproduction as represented by the line 25 coincides with the hues of the desired color reproduction, and the gamut 25 of the color reproduction obtained when both the coefficients for the first and second comparison-result data are identical to the gamut (22 in

In Embodiment 1 described above, the hue data r , g , b , y , m and c , and the maximum and minimum values β and α were calculated based on the inputted image data R_i , G_i and B_i so as to obtain the calculation terms for the respective hues, and the image data R_o , G_o , B_o are obtained after the calculation according to the formula (1), and the image data R_p , G_p , B_p are obtained after the gray scale conversion. As an alternative, after the image data R_o , G_o , B_o , or R_p , G_p , B_p are obtained, they may then be converted into complementary color data representing cyan, magenta and yellow, by determining 1's complement. In this case, the same effects will be realized.

Furthermore, in Embodiment 1 described above, the processing was performed by the hardware configuration of Fig. 1. Needless to say, the same processing can be performed by software in the color conversion device, and in this case, the same effects as those of Embodiment 1 will be provided.

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Embodiment 2

In Embodiment 1, the hue data r , g , b , y , m and c , and the maximum and minimum values β and α were calculated based on the inputted image data of red, green and blue so as to obtain the calculation terms for the respective hues, and after the matrix calculation, the image data red, green and blue were obtained. But the image data of red, green and blue may first be converted into complementary color data of cyan, magenta and yellow, by determining 1's complement of the input image data, and then color conversion may be executed by inputting the complementary color data of cyan, magenta and yellow.

Fig. 15 is a block diagram showing an example of configuration of a color conversion device of Embodiment 2 of the present invention. In describing Embodiment 2, the inputted image data of red, green and blue are denoted by R_j , G_j and B_j . Reference numerals 3, 4, 5, 6, 15a, 15b and 15c denote the same members as those described with reference to Fig. 1 in connection with Embodiment 1. Reference numeral 14 denotes a complement calculator; 1b, a minimum and maximum calculator for generating maximum and minimum values β and α of complementary color data and an identification code for indicating, among the six hue data, data which are zero; and 2b, a hue data calculator for calculating hue data r , g , b , y , m and c based on complementary color data C_i , M_i and Y_i from the complement calculator 14 and outputs from the minimum and maximum calculator 1b.

Next, the operation will be described. The complement calculator 14 receives the image data R_j , G_j and B_j , and outputs complementary color data C_i , M_i and Y_i obtained by determining 1's complements. The minimum and maximum calculator 1b outputs the maximum and minimum values β and

Then, the hue data calculator 2b receives the complementary color data C_i , M_i and Y_i and the maximum and minimum values β and α from the minimum and maximum calculator 1b, performs subtraction of

and outputs six hue data r , g , b , y , m and c . Here, at least two among these six hue data are zero. The identification code S1 outputted from the minimum and maximum calculator 1b is used for specifying, among the six hue data, data which is zero. The value of the identification code S1 depends on which of C_i , M_i and Y_i the maximum and minimum values β and α are. Relations between the data among the six hue data which are zero, and the values of the identification code S1 are the same as those in Embodiment 1, and thus further explanation will be omitted.

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The output of the polynomial calculator 3 is supplied to the matrix calculator 4, and the coefficient generator 5 generates the calculation coefficients $U(F_{ij})$ and fixed coefficients $U(E_{ij})$ for the polynomial data based on the identification code S_1 , and sends the same to the matrix calculator 4. The matrix calculator 4 receives the hue data c , m and y from the hue data calculator 2b, the polynomial data T_1 to T_5 from the polynomial calculator 3 and the coefficients U from the coefficient generator 5, and outputs the results of calculation according to the following formula (8) as image data C_1 , M_1 and Y_1 .

$$\begin{bmatrix} C1 \\ M1 \\ Y1 \end{bmatrix} = (E1j) \begin{bmatrix} c \\ m \\ y \end{bmatrix} + (F1j) \begin{bmatrix} T1 \\ T2 \\ T3 \\ T4 \\ T5 \end{bmatrix} \quad \dots (8)$$

The operation at the matrix calculator 4 is similar to that described with reference to Fig. 5 in connection with Embodiment 1, but the inputted hue data is c (or m, y), and C1 (or M1, Y1) is calculated and outputted. The detailed description thereof is therefore omitted.

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$$\begin{bmatrix} \text{Co} \\ \text{Mo} \\ \text{Yo} \end{bmatrix} = (\text{Eij}) \begin{bmatrix} \text{c} \\ \text{m} \\ \text{y} \end{bmatrix} + (\text{Fij}) \begin{bmatrix} \text{h1b} \\ \text{h1c} \\ \text{h1m} \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \quad \dots (2)$$

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h1r = min (m, y),
h1g = min (y, c),
h1b = min (c, m),
h1c = min (g, b),
h1m = min (b, r),
h1y = min (r, g),
h2ry = min (aq1*h1y, ap1*h1r),
h2rm = min (aq2*h1m, ap2*h1r),
h2gy = min (aq3*h1y, ap3*h1g),
h2gc = min (aq4*h1c, ap4*h1g),
h2bm = min (aq5*h1m, ap5*h1b), and
h2bc = min (aq6*h1c, ap6*h1b), and

```

The difference between the number of calculation terms in the formula (2) and the number of calculation terms in Fig. 15 is that Fig. 15 shows a method of calculation for

each pixel excluding the calculation terms which are of a value zero, while the formula (2) represents a general formula for a set of pixels. In other words, eighteen polynomial data for one pixel of the formula (2) can be reduced to five effective data, and this reduction is achieved by exploiting a characteristic of the hue data.

The combination of effective data is changed according to image data of the target pixel. For all image data, all the polynomial data can be effective.

The calculation terms output from the polynomial calculator based on the formula (2) are identical to those of the formula (1) in Embodiment 1. Thus, relations between the six hues and inter-hue areas and effective calculation terms are the same as those shown in Fig. 11A and Fig. 11B. Therefore, as in Embodiment 1, in the coefficient generator 5, by changing the coefficients for an effective calculation term for a hue or for an inter-hue area to be adjusted, only the target hue or inter-hue area can be adjusted. In addition, by changing the coefficients in the calculation coefficient generator 11 in the polynomial calculator 3, part of the inter-hue area where the calculation term in the inter-hue area is effective can be changed without giving any influence to the other hues.

Here, an example of coefficients generated by the coefficient generator 5 of Embodiment 2 are the coefficients $U(E_{ij})$ of the formula (5), as in Embodiment 1. If the coefficients $U(F_{ij})$ are all zero, color conversion is not executed. Also, if those of the coefficients $U(F_{ij})$ of the formula (7) which relate to the second-order calculation terms which are product terms are all zero, adjustment is performed based on the coefficients for the first and second comparison-result data, which are first-order calculation terms, and linear adjustment on only a hue or an inter-hue area can be achieved. By setting coefficients relating to a

first-order calculation term for a hue or an inter-hue area to be changed and setting other coefficients to zero, only the target hue or inter-hue area can be adjusted.

As apparent from the foregoing, by changing the coefficients for the product terms and first comparison-result data relating to specific hues, it is possible to adjust only the target hue among the six hues of red, blue, green, yellow, cyan and magenta, and by changing the coefficients for the second comparison-result data, it is possible to vary the colors in the six inter-hue areas of red-yellow, yellow-green, green-cyan, cyan-blue, blue-magenta, and magenta-red. The adjustment of each hue or inter-hue area can be achieved independently, i.e., without influencing other hues or other inter-hue areas.

Each of the foregoing product terms is a second-order calculation for chroma, and each of the first and second comparison-result data is a first-order calculation for chroma. Accordingly, by using the product term and the first and second comparison-result data, the non-linearity of an image-printing or the like can be varied for chroma.

Moreover, by performing the gray scale conversion at the gray scale converters 15a, 15b and 15c, it is possible to compensate for third-order or higher-order non-linearities, or complicated, non-linear characteristics (e.g., S-shaped characteristics) such as the one which liquid-crystal displays exhibit, and which can be obtained just by combining the first-order and second-order calculations.

Accordingly, it is possible to obtain color conversion methods or color conversion devices which can change the conversion characteristics flexibly, without requiring a large-capacity memory. It is noted that the gray scale converters can be realized by a one-dimensional look-up table, and its size is much smaller than the three-

dimensional look-up table.

Furthermore, in Embodiment 2 described above, the processing was performed by the hardware configuration of Fig. 15. Needless to say, the same processing can be performed by software in the color conversion device, and in this case, the same effects as those of Embodiment 2 will be provided.

Moreover, the conversion characteristics of the gray scale converters 15a, 15b and 15c can be determined taking into consideration the characteristics of the output device connected to receive the output of the color conversion device, and are not restricted to gamma correction characteristics, and may be a linear characteristics in an extreme case. However, even in the case of a linear characteristics, by varying the inclination, the level balance of the output signals can be adjusted.

Embodiment 3

In Embodiment 1, part of an example of configuration of the matrix calculator 4 is as shown in the block diagram of Fig. 5, and the hue data and the respective calculation terms and the minimum value α among the image data R_i , G_i and B_i which is achromatic data are added together to produce the image data R_o , G_o , B_o , as shown in the formula (1). It is possible to adopt a configuration shown in Fig. 16 in which coefficients for the minimum value α which is achromatic data are generated in the coefficient generator and the matrix calculation is performed on the minimum value α as well, to adjust the achromatic component.

Fig. 16 is a block diagram showing an example of configuration of a color conversion device of Embodiment 3 of the present invention. In the figure, reference numerals 1, 2, 3, 15a, 15b and 15c denote members identical to those described with reference to Fig. 1 in connection with

Embodiment 1. Reference numeral 4b denotes a matrix calculator, and 5b denotes a coefficient generator.

The operation will next be described. The determination of the maximum value β , the minimum value α , and the identification code S1 from the inputted data at the minimum and maximum calculator 1, the calculation of the six hue data at the hue data calculator 2, and the determination of the calculation terms at the polynomial calculator 3 are identical to those of Embodiment 1, and detailed description thereof is therefore omitted.

The coefficient generator 5b in Fig. 16 generates the calculation coefficients U (Fij) and the fixed coefficients U (Eij) of the polynomial data based on the identification code S1 and sends them to the matrix calculator 4b. The matrix calculator 4b receives the hue data r, g, and b from the hue data calculator 2, the polynomial data T1 to T5 from the polynomial calculator 3, the minimum value α from the minimum and maximum calculator 1, and the coefficients U from the coefficient generator 5b, and performs calculation thereon. The equation used for the calculation for adjusting the achromatic component as well is represented by the following formula (9).

$$\begin{bmatrix} R_o \\ G_o \\ B_o \end{bmatrix} = (E_{ij}) \begin{bmatrix} r \\ g \\ b \end{bmatrix} + (F_{ij}) \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ \alpha \end{bmatrix} \quad \dots(9)$$

In the formula (9), for (Eij), i = 1 to 3 and j = 1 to 3, and for (Fij), i = 1 to 3 and j = 1 to 6.

Fig. 17 is a block diagram showing an example of configuration of the matrix calculator 4b. In Fig. 17, reference numerals 12a to 12f and 13a to 13f denote members identical to those in the matrix calculator 4 of Embodiment

Next, the operation will be described. The multipliers 12a to 12f receive the hue data r , the polynomial data T1 to T5 from the polynomial calculator 3 and the coefficients $U(E_{ij})$ and $U(F_{ij})$ from the coefficient generator 5, and then output the products thereof. The adders 13a to 13e add the products and sums. These operations are identical to those of the matrix calculator 4 in Embodiment 1. The multiplier 12g receives the minimum value α among the image data R_i , G_i and B_i , from the minimum and maximum calculator 1 which corresponds to the achromatic component, and the coefficients $U(F_{ij})$ from the coefficient generator 5b, and performs multiplication, and outputs the product to the adder 13f, where the product is added to the output of the adder 13e, and the sum total is output as the image data R_o . In the example of Fig. 17, if the hue data r is replaced by g or b , the image data G_o or B_o is calculated.

The equation for determining the image data is represented by the following formula (3).

$$\begin{bmatrix} R_o \\ G_o \\ B_o \end{bmatrix} = (E_{ij}) \begin{bmatrix} r \\ g \\ b \end{bmatrix} + (F_{ij}) \begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \\ \alpha \end{bmatrix} \quad \dots(3)$$

In the formula (3), for (E_{ij}) , $i = 1$ to 3 and $j = 1$ to 3, and for (F_{ij}) , $i = 1$ to 3 and $j = 1$ to 19.

The difference between the number of calculation terms in the formula (3) and the number of calculation terms in Fig. 16 is that, as in Embodiment 1, Fig. 16 shows a method of calculation for each pixel excluding the calculation terms which are of a value zero, while the formula (3) represents a general formula for a set of pixels. In other words, nineteen polynomial data for one pixel of the formula (3) can be reduced to six effective data, and this reduction is achieved by exploiting a characteristic of the hue data.

The combination of effective data is changed according to image data of the target pixel. For all image data, all the polynomial data can be effective.

If all the coefficients relating to the minimum value α are "1", the achromatic data is not converted, and will be of the same value as the achromatic data in the inputted data. If the coefficients used in the matrix calculation are changed, it is possible to choose between reddish black,

bluish black, and the like, and the achromatic component can be adjusted.

As apparent from the foregoing, by changing the coefficients for the product term and first comparison-result data relating to specific hues, and the second comparison-result data relating to the inter-hue areas, it is possible to adjust only the target hue or inter-hue area among the six hues of red, blue, green, yellow, cyan and magenta, and the six inter-hue areas, without influencing other hues and inter-hue areas. By changing the coefficients relating to the minimum value α which is the achromatic data, it is possible to adjust only the achromatic component without influencing the hue components, and choose between a standard black, reddish black, bluish black and the like.

In Embodiment 3 described above, the image data Ro, Go and Bo are obtained after the calculation according to the formula (3), and image data Rp, Gp, Bp are obtained after the gray scale conversion. As an alternative, after the output image data Ro, Go, Bo or Rp, Gp, Bp are obtained, they may be converted to data representing cyan, magenta and yellow, by determining 1's complement. If the coefficients used in the matrix calculation can be changed for the respective hues, the inter-hue areas, and the minimum value α which is achromatic data, effects similar to those discussed above can be obtained.

As in Embodiment 1 described above, in Embodiment 3, as well, the same processing can be performed by software in the color conversion device, and in this case, the same effects as those of Embodiment 3 will be provided.

Moreover, the conversion characteristics of the gray scale converters 15a, 15b and 15c can be determined taking into consideration the characteristics of the output device connected to receive the output of the color conversion

device, and are not restricted to gamma correction characteristics, and may be a linear characteristics in an extreme case. However, even in the case of a linear characteristics, by varying the inclination, the level balance of the output signals can be adjusted.

Embodiment 4

Embodiment 2 was configured to add the hue data, the calculation terms, and the minimum value α which is achromatic data, as shown in the formula (2). As an alternative, the configuration may be such that coefficients for the minimum value α which is achromatic data is generated at the coefficient generator and the matrix calculation is performed on the minimum value α as well, as shown in Fig. 18, so that the achromatic component is thereby adjusted.

Fig. 18 is a block diagram showing an example of configuration of color conversion device according to Embodiment 4 of the invention. In the figure, reference numerals 14, 1b, 2b, 3, 15a, 15b and 15c denote members identical to those described with reference to Fig. 15 in connection with Embodiment 2, and reference numerals 4b and 5b denote members identical to those described with reference to Fig. 16 in connection with Embodiment 3.

The operation will next be described. The image data R_j , G_j , B_j are input to the complement calculator 14 to obtain the complementary data C_i , M_i , Y_i by the process of determining 1's complement. The determination of the maximum value β , the minimum value α and the identification code S_1 at the minimum and maximum calculator 1b, the calculation of the six hue data at the hue data calculator 2b, and the determination of the calculation terms at the polynomial calculator 3 are identical to those in the case of the complementary data C_i , M_i , Y_i in

The coefficient generator 5b in Fig. 18 generates the calculation coefficients U (F_{ij}) and the fixed coefficients U (E_{ij}) of the polynomial data based on the identification code $S1$ and sends them to the matrix calculator 4b. The matrix calculator 4b receives the hue data c , m , and y from the hue data calculator 2b, the polynomial data $T1$ to $T5$ from the polynomial calculator 3, the minimum value α from the minimum and maximum calculator 1, and the coefficients U from the coefficient generator 5b, and performs calculation thereon. The equation used for the calculation is represented by the following formula (10), and the achromatic component is adjusted.

$$\begin{bmatrix} \text{Co} \\ \text{Mo} \\ \text{Yo} \end{bmatrix} = (\text{E1j}) \begin{bmatrix} \text{c} \\ \text{m} \\ \text{y} \end{bmatrix} + (\text{F1j}) \begin{bmatrix} \text{T1} \\ \text{T2} \\ \text{T3} \\ \text{T4} \\ \text{T5} \\ \alpha \end{bmatrix} \quad \dots (10)$$

The operation at the matrix calculator 4b is similar to that described with reference to Fig. 17 in connection with Embodiment 3, but the inputted hue data is c (or m, y), and Co (or Mo, Yo) is calculated and outputted. The detailed description thereof is therefore omitted.

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$$\begin{bmatrix} Co \\ Mo \\ Yo \end{bmatrix} = (E_{ij}) \begin{bmatrix} c \\ m \\ y \end{bmatrix} + (F_{ij}) \begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \\ \alpha \end{bmatrix} \quad \dots (4)$$

In the formula (4), for (E_{ij}) , $i = 1$ to 3 and $j = 1$ to 3, and for (F_{ij}) , $i = 1$ to 3 and $j = 1$ to 19.

The difference between the number of calculation terms in the formula (4) and the number of calculation terms in Fig. 18 is that, as in Embodiment 2, Fig. 18 shows a method of calculation for each pixel excluding the calculation terms which are of a value zero, while the formula (4) represents a general formula for a set of pixels. In other words, nineteen polynomial data for one pixel of the formula (4) can be reduced to six effective data, and this reduction is achieved by exploiting a characteristic of the hue data.

The combination of effective data is changed according to image data of the target pixel. For all image data, all the polynomial data can be effective.

If all the coefficients relating to the minimum value α are "1", the achromatic data is not converted, and will be of the same value as the achromatic data in the inputted data. If the coefficients used in the matrix calculation are changed, it is possible to choose between reddish black,

bluish black, and the like, and the achromatic component can be adjusted.

As apparent from the foregoing, by changing the coefficients for the product term and first comparison-result data relating to specific hues, and the second comparison-result data relating to the inter-hue areas, it is possible to adjust only the target hue or inter-hue area among the six hues of red, blue, green, yellow, cyan and magenta, and the six inter-hue areas, without influencing other hues and inter-hue areas. By changing the coefficients relating to the minimum value α which is the achromatic data, it is possible to adjust only the achromatic component without influencing the hue components, and choose between a standard black, reddish black, bluish black and the like.

As in Embodiment 1 described above, in Embodiment 4, as well, the same processing can be performed by software in the color conversion device, and in this case, the same effects as those of Embodiment 4 will be provided.

Moreover, the conversion characteristics of the gray scale converters 15a, 15b and 15c can be determined taking into consideration the characteristics of the output device connected to receive the output of the color conversion device, and are not restricted to gamma correction characteristics, and may be a linear characteristics in an extreme case. However, even in the case of a linear characteristics, by varying the inclination, the level balance of the output signals can be adjusted.

Embodiment 5

In Embodiment 2 and Embodiment 4, the image data C_i , M_i , Y_i are obtained by determining 1's complement of input image data R_j , G_j and B_j . Similarly, the image data R_i , G_i , B_i used in Embodiment 1 may be those obtained by 1's

complement of input image data representing cyan, magenta and yellow, C_j , M_j and Y_j . For the determination of the 1's complement of the input image data C_j , M_j , Y_j , a complement calculator which is similar to the complement calculator 14 in Fig. 15 or Fig. 18 but which receives the image data C_j , M_j , Y_j may be used. Fig. 19 shows an example of color conversion device having such a complement calculator denoted 14b. Apart from the addition of the complement calculator 14b, the configuration of the color conversion device of Fig. 19 is similar to the color conversion device of Fig. 1. Similar modification may be made to the color conversion device of Embodiment 3 shown in Fig. 16.

Modifications described in connection with Embodiment 1 to Embodiment 4 can also be applied to Embodiment 5.